GASIFICATION TECHNOLOGIES: THE PATH TO CLEAN, AFFORDABLE ENERGY IN THE 21ST CENTURY

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INTRODUCTION

The production of gas from coal dates back as far as the end of the eighteenth century, and by the middle of the nineteenth century, the underlying principals of gasification were fairly well understood. Gasification was very prominent in the latter part of the nineteenth and the twentieth centuries for the production of town gas for residential and industrial use. Gasification for the production of town gas has nearly vanished as economically advantageous resources and delivery of clean natural gas and oil fuels has satisfied that need. New applications of gasification technologies in the manufacturing and industrial sectors have been found, forcing new developments by gasification technology vendors to maintain a competitive advantage. Such developments have sustained gasification as an important industrial process for many years and have included the participation of the Department of Energy's R&D program and the Clean Coal Technology program.

The gasification process converts solid or liquid hydrocarbon feedstocks, often of lesser market value than premium gas or liquid fuels, into a synthesis gas that is suitable for use for its fuel value in producing electricity or to convert to chemicals, hydrogen, or liquid fuels. Continued enactment of stricter regulations on the manufacturing sector, coupled with opportunities and pressures to more effectively use the low-quality portion of oil resources will combine with increasing prices for delivered gas to encourage the search for appropriate technology solutions. In response, further technological advances will push gasification to even greater heights in the twenty-first century.

GASIFICATION TODAY

Today, gasification is widely deployed throughout the world in many industrial settings. Currently, there exists 128 plants worldwide with 366 operating gasifiers.[1] The vast majority of these facilities are located in Western Europe, the Pacific Rim, Africa, and North America. Combined, these plants generate over 42,000 MWth of synthesis gas. During the next 5 years, an additional 33 plants with 48 gasifiers are expected to be constructed adding another 18,000 MWth of synthesis gas capacity. Most of this expected growth will occur in the developing nations in the Pacific Rim as the need for further electrification of these nations' economies grow. The second largest growth area is expected to be in Western Europe where refineries will need to reduce fuel oil production. Growth in North America will be about half of that in Europe and will be concentrated in the refining industry. Very little or no growth is anticipated to occur in Africa or other regions of the world.

Figure 1 illustrates the worldwide historical growth in gasification capacity since 1970 as well as the future additions through 2005. Almost all of the gasification capacity through the mid-1970s can be attributed to the 19 Lurgi gasifiers operating at Sasol in South Africa. The relatively large increases in capacity in the latter part of the 1970s and the early 1980s represent the startup of 80 gasifers associated with Sasol II and III, representing a combined increase of nearly 8,300 MWth of synthesis gas capacity. A small increase in capacity also occurred in the early 1980's with the commissioning of 14 Lurgi gasifiers at the Dakota Gasification plant in Buelah, ND, adding another 1500 MWth of capacity. Following this, capacity remained relatively flat for over a decade. However, within a few short years, capacity increased by almost 50% and is expected to grow by nearly 60% in the next 5 years. This tremendous rise in capacity is expected to continue beyond 2005.

Gasification technologies are capable of processing any carbon-based feedstock to produce synthesis gas for the production of electricity, steam, hydrogen, fuels, and chemical. Coal and petroleum residuals are by far the dominant feedstocks, together accounting for over 70% of the synthesis gas capacity. Most of the coal is consumed by Sasol and Dakota Gasification. Natural gas is also an important feedstock, accounting for about 20% of today's capacity, and is used almost exclusively in the production of chemicals. Over the next several years, most of the growth in capacity will be from the gasification of coal and petroleum residuals, with a small fraction from petroleum coke. The growth in these feedstocks, however, will be used primarily to produce electricity, with the use of synthesis gas for the production of electricity approaching that of chemicals. No capacity additions are projected for natural gas.

TECHNOLOGY DRIVERS

Gasification has many positive attributes, compared to other technologies, that have helped to stimulate the current market. As mentioned above, gasification is the only technology that offers both upstream (feedstock flexibility) and downstream (product flexibility) advantages. All carbon-containing feedstocks including hazardous wastes, municipal solid waste and sewage sludge, biomass, etc., can be readily gasified after proper preparation to produce clean synthesis gas for further processing. Because of its ability to use low-cost feedstocks, gasification is the technology of choice for many industrial applications such as in refineries. IGCC, and gasification processes in general, is also the only advanced power generation technology capable of coproducing a wide variety of commodity and premium products, in addition to electricity, to meet future market requirements. It is this ability to produce value-added products that has made gasification economical in selected situations and will be a key driver in a deregulated power market.

Compared to combustion systems, IGCC is the most efficient and environmentally friendly technology for the production of low-cost electricity from solid feedstocks and can be made to approach that of natural gas combined cycle plants. Further increases in efficiency can be achieved through integration with fuel cells. These higher efficiencies translate to lower operating costs and carbon dioxide emissions. In addition, the gasification process can be readily adapted with advanced technologies for the concentration of CO_2 with little impact on cost and thermal efficiency. The ability of a technology to achieve higher efficiencies and concentrate CO_2 with minimal impact on the cost of final products will be major factors in technology selection for future energy plants.

Because gasification operates at high pressure with a reducing atmosphere, the products from the gasifier are more amenable to cleaning to reduce ultimate emissions of sulfur and nitrogen oxides as well as other pollutants than those from combustion processes. In general, the volume of the fuel gas processed in an IGCC plant for contaminant removal is typically one-third that from a conventional power plant. Processing lower volumes of gas translates to lower capital cost for pollution prevention. The removal of sulfur, nitrogen, and other contaminants from the reducing gas is also much easier than from combustion products. This results in sulfur and nitrogen oxide emissions being more than an order of magnitude less than those of conventional combustion processes. Gasification plants can also be configured to reach near-zero levels of emissions when required.

Unlike that from combustion processes, the by-product ash and slag from the gasification technologies have also been shown to be nonhazardous. As such, the material can be readily used for landfill without added disposal cost or can be used in construction materials or further processed to produce value-added products.

Although current cost for greenfield sites are high, gasification processes can be economically integrated into existing refineries and chemical plants. Through proper integration and the use of existing infrastructure, the overall cost of a project can be significantly reduced. Through deployment in such environments, additional knowledge and experience will be gained, thereby reducing capital and operating and maintenance costs for future facilities.

GASIFICATION IN TOMORROW'S WORLD

More intense competition resulting from deregulation, stricter environmental laws on the emissions of sulfur and nitrogen oxides, hazardous air pollutants, and particulates, tighter regulations on product end-use applications, and the potential for future worldwide greenhouse gas emission treaties will have significant consequences on industry and society alike. To be prepared to respond to these issues when required, the U.S. Department of Energy has unveiled its Vision 21 program.[2] This comprehensive and aggressive program seeks to achieve substantial improvements in process efficiencies, reduce emissions of sulfur and nitrogen oxides, particulates, and hazardous air pollutants to near-zero levels, capture and sequester carbon dioxide, utilize all available carbon-based feedstocks, and produce a wide variety of commodity and specialty products to meet any market application. These goals are expected to be accomplished at product costs that are equal or lower than that in today's market.

Of all advanced technologies currently under development, gasification-based technologies are the only ones that have the potential to achieve all of these ambitious goals simultaneously. As a result, gasification is considered to be the cornerstone technology of the Vision 21 program. To confront these external forces and achieve the goals, not only will continual improvement need to be made as new units are employed, but new advanced, and even step-out, technologies will have to be developed during the next decade.

ACHIEVING THE VISION

To achieve the vision set out above, the DOE's Gasification Technologies Program has developed a comprehensive and aggressive program aimed at making gasification the technology of choice for future energy plants.[3] Figure 2 presents a capsule summary of the issues that need to be addressed for gasification-based processes to meet the above goals. Some of the technologies being developed in the Gasification Technologies program to address these issues, and more importantly, those technologies that are critical to achieving the above performance goals are described below. Critical technologies such as fuel cells and turbines are being addressed in other DOE programs. The proper integration of all of these technologies are necessary to achieve the vision.

Advanced Air Separation

Air separations for the production of oxygen is a very capital and operating cost intensive operation, usually accounting for 15% or more of total capital cost while consuming substantial quantities of electricity for air compression. Any technology that can offer a significant reduction in the cost of oxygen will have a substantial impact on the overall economics of gasification-based process. One novel approach that has shown tremendous potential is the use of high temperature mixed conducting ceramic membranes. The membranes simultaneously conduct oxygen ions and electrons through the membrane, thereby obviating the need for an external circuit to drive the separation. The technology produces pure oxygen. Properly integrated into the process, the technology has shown potential for significant cost reductions as well as improvements in plant efficiency.[4] Two projects are currently in progress to develop this technology.

Ultra-Clean Synthesis Gas

Ultra-clean synthesis gas is needed not only to meet the near-zero emission goals of Vision 21, but is also required to meet the stringent gas quality requirements needed for use in fuel cell applications or for the conversion to transportation fuels and/or chemicals. The cost to achieve these goals must be no more than that of current commercial technologies and must not incur an energy penalty on the process. The current targets are: Sulfur - <60 ppb; Ammonia - <10 ppm; and Chlorine - <10 ppb. The operating range for the processes should stay above the condensation temperature of the moisture in the gas to achieve higher process efficiencies. The DOE recently awarded two projects to investigate novel process concepts while simultaneously redirecting its hot gas sorbent development program to focus on achieving greater levels of contaminant removal.

Coproduction

The production of more than one product offers the unique opportunity to adjust to swings in market demand for products while simultaneously maximizing the utilization of the capital investment. Through proper integration, coproduction can offer higher process efficiencies with little added capital.[5] Gasification-based processes are the only advanced power generation technologies that are capable of producing multiple products while simultaneously achieving all of the other performance targets of Vision 21. The DOE has undertaken an aggressive program to accelerate the deployment of coproduct processes schemes through its Early Entrance Coproduction Plant initiative. The processes are considered to be pre-Vision 21 energy plants, meeting some but not all performance requirements. Three project teams, each consisting of strong industrial participants, are focusing on developing their own unique scheme for the production of electricity and methanol (one project) and electricity and fuels (two projects). It is believed that through the operation of these initial plants, successive plants will be built and operated, each building upon the knowledge gained previously and incorporating new advances. Through successive deployments, coproduction will become a viable option for future energy plants.

Hydrogen and Carbon Dioxide Separation

To achieve very high efficiencies and to capture carbon dioxide for sequestration or utilization, advanced technologies need to be developed that simultaneously produce hydrogen for use with fuel cells or hydrogen turbines and concentrate carbon. Two approaches are being investigated, i.e., a high temperature and a low temperature approach. The high temperature approach focuses on the use of ceramic membranes that can affect the water-gas shift reaction in the synthesis gas steam while simultaneously separating the hydrogen. The resulting pure hydrogen stream can be fed directly to a solid oxide fuel cell while the concentrated carbon dioxide steam can be sequestered. Both small pore molecular sieve membranes and proton transfer membranes are being developed. The second approach focuses on the formation of removing carbon dioxide from a shifted synthesis gas by forming CO_2 hydrates. Again, a pure stream of hydrogen is recovered along with a high pressure stream of CO_2.

PROCESS ECONOMICS

As a result of DOE's Clean Coal Demonstration program, significant progress has been made in reducing the costs and risks of gasification-based processes. Today, the cost of a first-of-a-kind integrated gasification combined cycle plant is projected to be about \$1,250/kWe as shown by the curve on the left in Figure 3. Through successive deployment of this technology, the cost is expected to be reduced to about \$1,000/kWe. This figure also shows that further cost reductions and efficiency improvements can be realized through the development of advanced technologies such as advanced gas turbines, hot gas cleanup, and advanced air separation membranes. As shown by the curve on the right, potential exists for achieving a cost of about \$850/kWe, that which is considered by industry to be competitive to natural gas combined cycle.

Table 1 provides a capsule summary of the result of study focusing on the cost of producing hydrogen from coal, while simultaneously concentrating CO_2, using conventional as well as advanced technologies.[6] Using conventional commercial technologies for shifting the synthesis gas and gas separation results in a cost of about \$5.60/MMBtu (\$5.28/GJ). Incorporating the use of higher pressure gasifiers, high temperature gas filtration technology, and advanced ceramic membranes can result in a substantial reduction in the cost of hydrogen. This final cost is still somewhat higher than the cost of hydrogen from natural gas at today's prices, but will be increasingly competitive as gas prices rise.

The above two studies clearly show that through the development of advanced technologies, gasification-based process can be cost competitive with other technologies and can be configured to economically produce hydrogen and, at the same time, concentrate CO_2 to more readily sequester or use the CO_2. What is needed is a mechanism to support the demonstration and commercialization of these new concepts through the first few plants to achieve the benefits of the learning curve and reduce the technical and economic risks to levels acceptable to industry and financial institutions.

CONCLUSIONS

By 2015, gasification-based technologies using all carbon-based feedstocks are expected to have gained global acceptance, penetrating not only the refining and chemical industries but also the electric utility, pulp and paper, and steel industries. The product market for gasification will not only show continued growth in the power generation and chemicals sectors but will find significant opportunities for growth in the transportation fuel productions. Ultimately, gasification will serve as a key technology in efforts to control greenhouse gas emissions and will be an important technology in the transition to a hydrogen-based economy. Gasification-based process will be the technology of choice in the future because of their low cost and superior environmental performance, and their adaptability to meet future market requirements for feedstocks and products.

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Table 1
Synthesis Gas and Hydrogen Plant Performance and Cost Summary

	Synthesis Gas	Hydrogen (Conv.)	Hydrogen (Adv.)	Transport (Adv.)
Coal Feed, dry, t/d	2268	2268	2268	2268
Oxygen Feed, 99% (cryogenic), t/d	1927	1947	2747	2929
Hydrogen/Synthesis Gas Production, t/d	4479	288	370	354
Gypsum/Sulfuric Acid Prod., t/d	210	208	459	459
Net Power Production, MW	-9	36	42	48
Equivalent Thermal Efficiency, %	82.5	63.1	80.5	77.9
Total Plant Cost, K$	253,445	374,273	306,605	297,044
Product Cost, $/GJ	3.24	5.28	3.84	3.66

Figure 1
Cumulative Worldwide Gasification Capacity

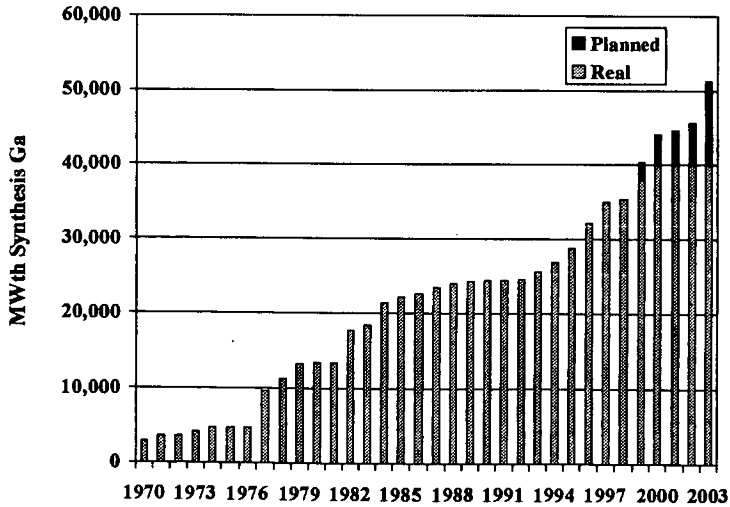

Figure 2
Gasification Technology Issues

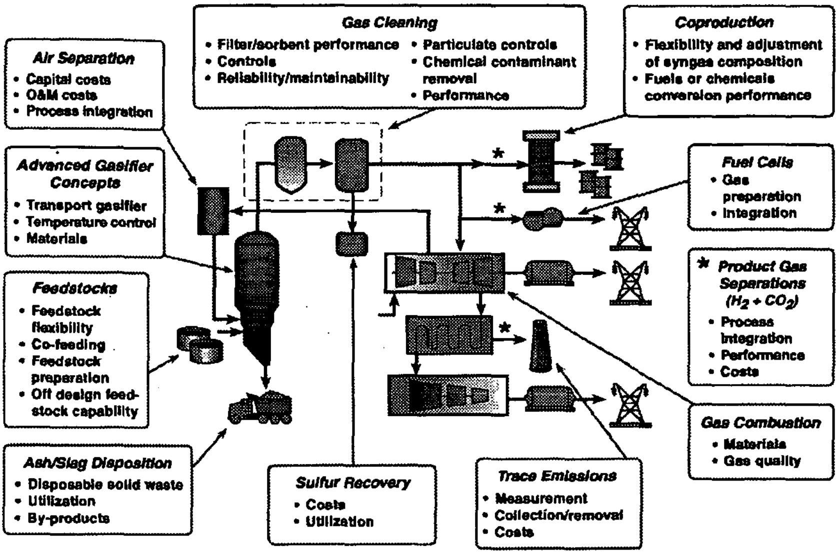

Figure 3
Effect of Technological Developments and Technology Deployment on the Cost of IGCC Plants